ASH BEHAVIOR IN ENTRAINED-FLOW COAL GASIFIER AND DEVELOPMENT OF 3D COMPUTER SIMULATOR

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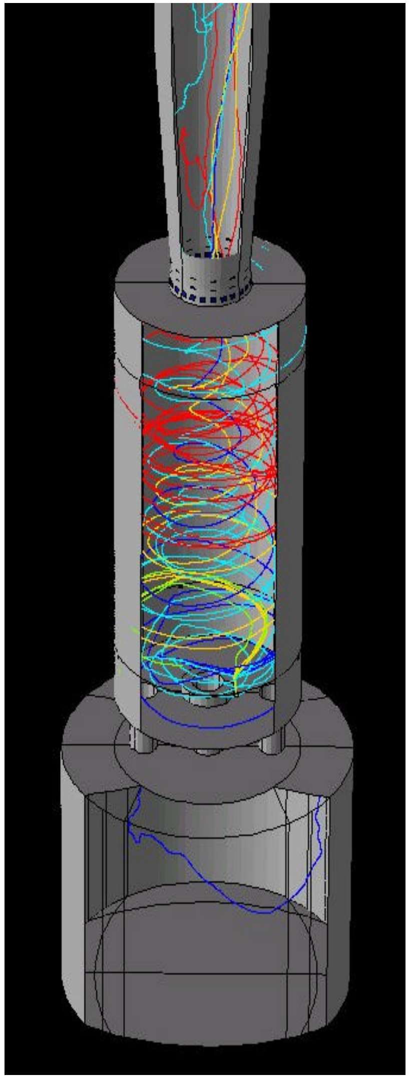
INTRODUCTION



Development of coal gasification simulator is carrying out to analyze and predict thermal, chemical and physical phenomena of entrained-flow coal gasifiers.

Devolatilization, char gasification reactions and ash particle collisions to the wall occur simultaneously in the gasification reactor.

In particular, ash deposition causes serious problems for a stable operation of gasifiers. Deposit formation at heat exchanger has a significant impact on the heat transfer performance.

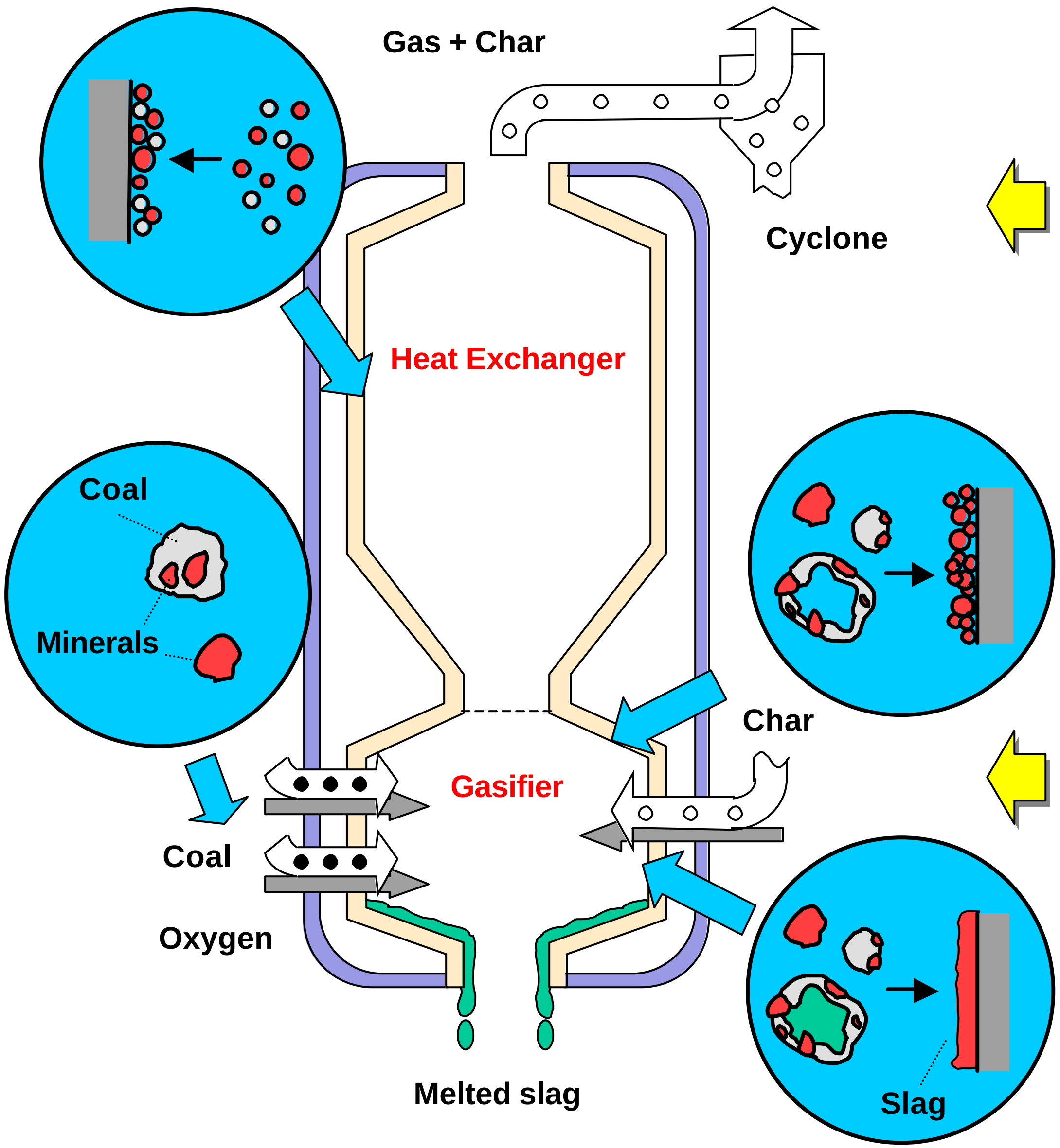
This presentation focuses on the modeling of ash behavior at reactor and heat exchanger and their incorporation into the 3D computer simulation.

Calculated results were compared with the actual data measured at HYCOL pilot plant (50 ton/day).

PRESENTATION OUTLINE

- Introduction
- Ash Behavior in Gasifier
- Modeling of Ash Behavior
  - Ash Formation and Deposition at Gasification Reactor
  - Particles Adhesion at Heat Exchanger
- Computer Simulation Incorporated to Ash Model
- Conclusion

ASH BEHAVIOR IN GASIFIER



Adhesion of Char particles at Heat Exchanger

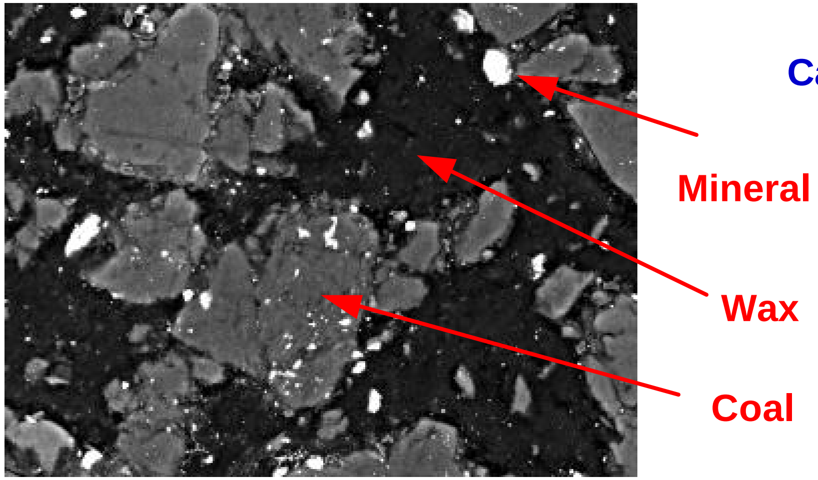
- Particle adhesion reduce heat recovery.

Slag Growth at Throat Area of Gasifier

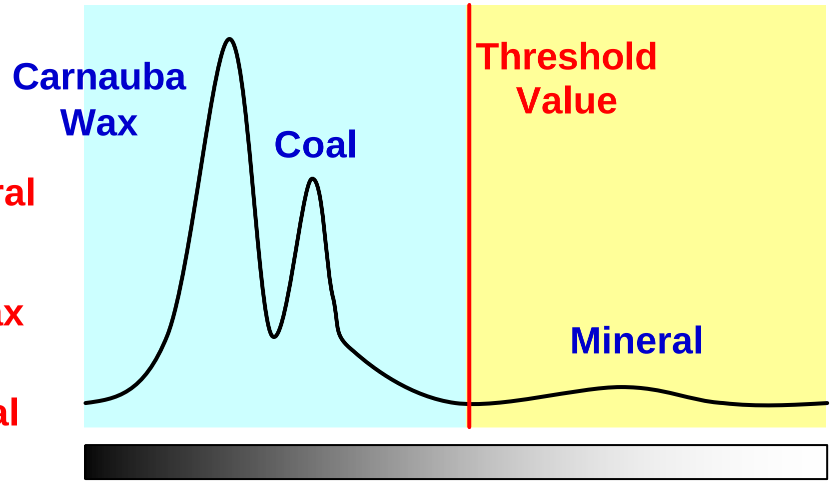
- Intensive slagging lead to plant shutdown.

CCSEM ANALYSIS

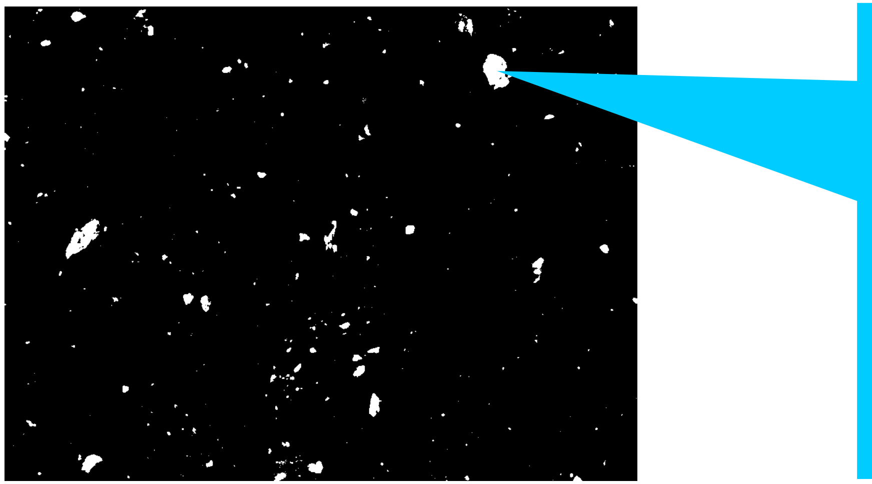
Back Scattered Electron Image



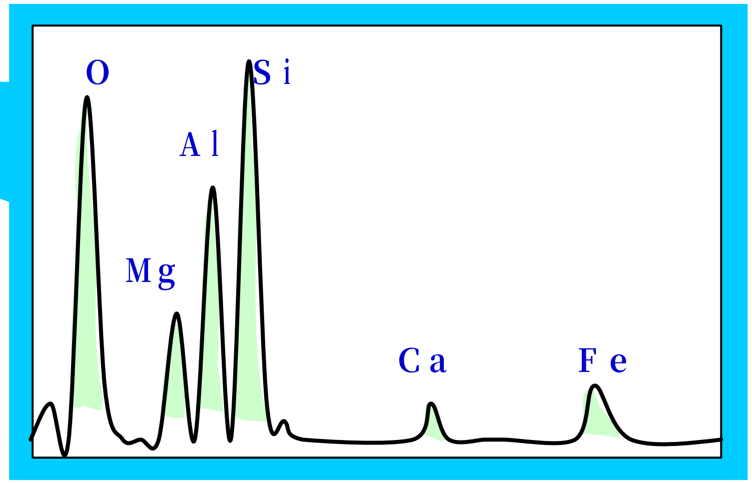
Distribution of Brightness Levels



Binary Image

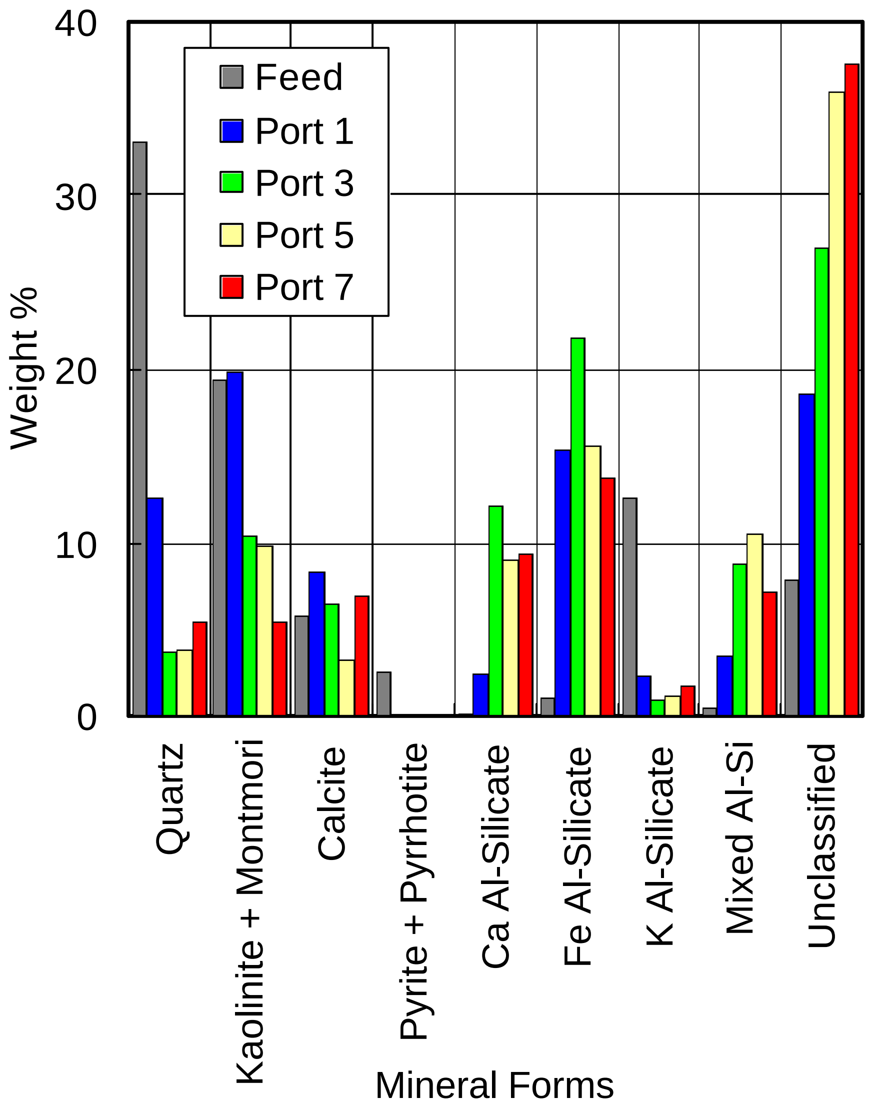


EDX Spectrum

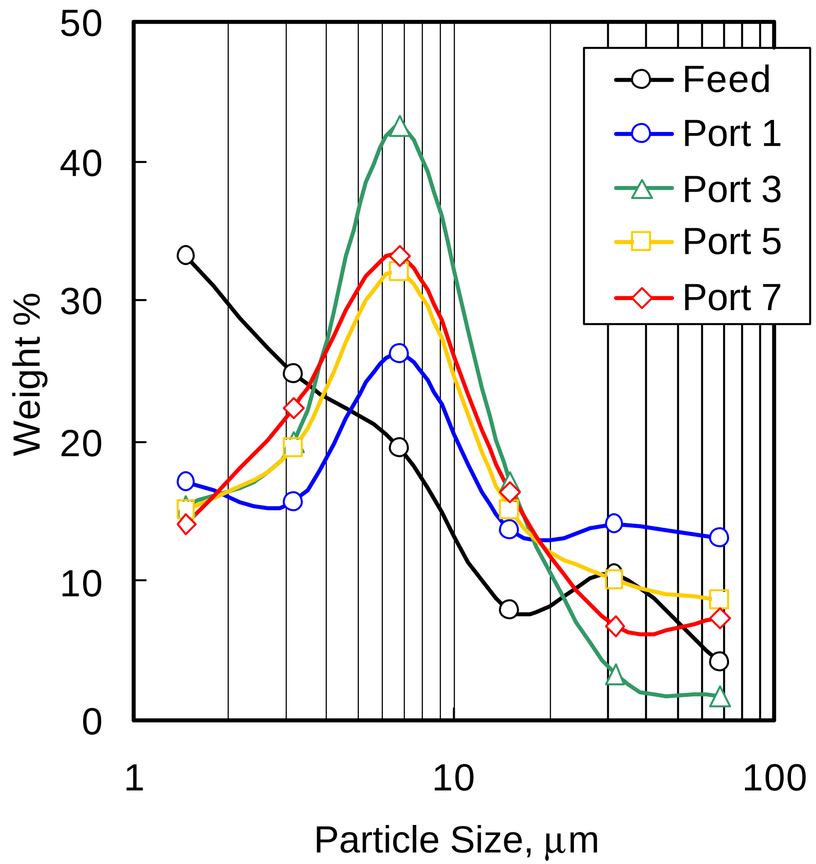


CHANGE OF FORM AND SIZE

Chemical Forms



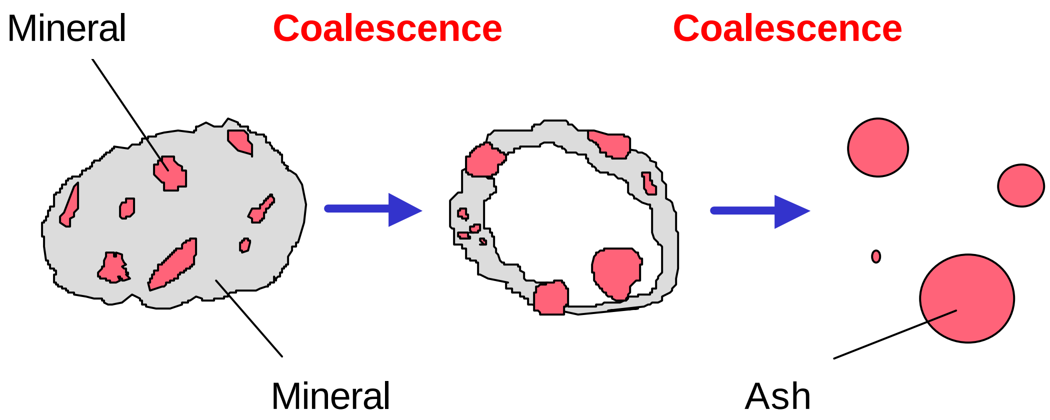
Size Distribution



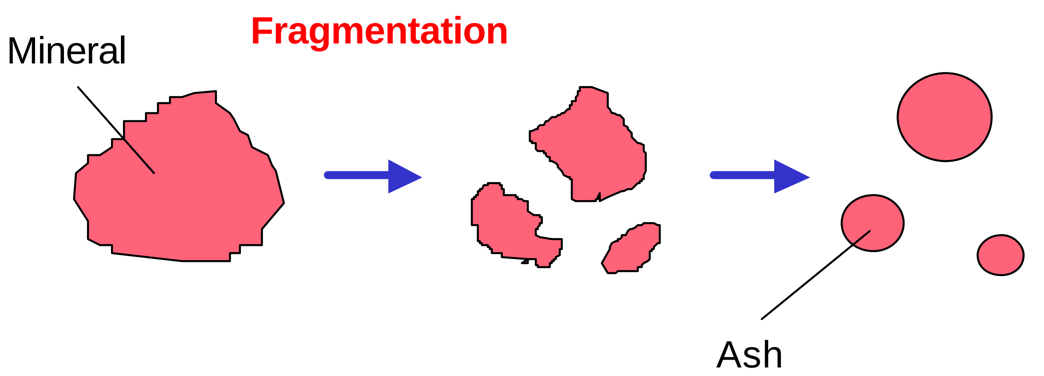
Quartz and Kaolinite unite with Ca or Fe containing minerals to produce Ca/Al-Silicate, Fe/Al-Silicate and Unclassified.

ASH FORMATION MODEL

Included Minerals



Excluded Minerals

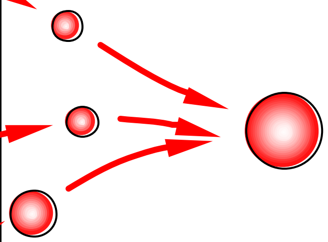


1. Several included minerals in coal melt together and create a new particle with a chemical composition equal to the united composition of selected minerals. The size of created new particle is also calculated by a combination of selected minerals.
2. Excluded minerals randomly fragment to several particles by thermal shock due to the introduction into high temperature atmosphere.
3. There is no reaction between included and excluded minerals.

CALCULATION FROM CCSEM DATA

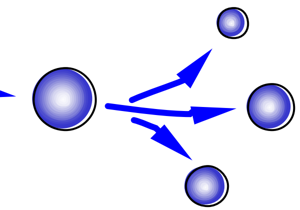
CCSEM Data of Feed Coal

No.	Composition												Ave. Diameter	Area	Chemical Category	In/Ex
	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ba	Ti				
1	0	0	39	52	1	3	0	0	0	1	3	1	1.3	1.3	Kaolinite	In
2	0	0	43	51	0	0	0	1	0	1	2	2	1.7	2.2	Kaolinite	In
3	7	0	22	65	1	0	0	1	4	0	0	0	1.8	2.5	Na Al/Si	In
4	0	3	19	54	0	3	0	7	0	0	0	14	1.2	1.1	Unclassified	In
5	0	0	15	80	0	0	3	0	0	1	0	1	1.2	1.2	Unclassified	In
6	1	6	17	5	25	0	1	0	41	0	0	4	3.5	9.7	Ca-Al-P	Ex
7	1	0	23	66	2	0	1	2	3	1	0	1	1.2	1.1	Al/Si	In
8	0	0	0	99	0	0	0	0	0	0	0	1	4.1	13.4	Quartz	In
9	0	9	32	47	0	0	0	0	2	0	0	10	2.0	3[illegible]	[illegible]	[illegible]
10	1	1	17	60	0	0	0	18	2	0	0	1	1.4	1[illegible]	[illegible]	[illegible]
11	0	0	37	57	0	4	0	1	0	0	0	1	1.9	2[illegible]	[illegible]	[illegible]
12	1	1	38	48	1	0	0	3	2	2	1	3	1.1	1.0	Kaolinite	Ex
13	0	2	5	0	30	0	0	0	61	0	2	0	2.5	5.1	Apatite	In
14	0	0	0	97	0	0	0	1	0	0	2	0	4.0	12.4	Quartz	Ex
15	0	8	21	48	1	1	7	0	5	0	0	9	1.6	1.9	Mixed Si	In
16	1	0	2	2	4	2	4	0	82	0	0	3	1.4	1.6	Calcite	In
17	0	0	14	64	0	0	0	19	2	1	0	0	4.9	19.2	Unclassified	In
18	2	1	6	89	0	0	0	0	0	0	1	1	6.0	27.9	Quartz	Ex
19	0	0	0	97	0	0	0	1	0	0	1	1	5.2	21.6	Quartz	Ex
20	0	0	0	3	1	2	0	2	89	1	1	1	7.0	38.4	Calcite	In
21	0	2	38	41	2	0	3	2	7	0	1	4	9.2	66.0	Ca Al/Si	In
22	0	0	42	54	0	2	0	0	1	0	0	1	15.5	189.9	Kaolinite	Ex
23	0	8	1	0	1	4	3	0	80	1	2	0	4.8	18.2	Dolomite	Ex
24	0	1	45	0	29	0	3	0	19	1	1	1	6.3	30.8	Ca-Al-P	In
25	0	0	1	33	1	0	1	0	64	0	0	0	26.7	561[illegible]	[illegible]	[illegible]
26	1	0	0	95	0	2	1	0	0	1	0	0	67.6	3589[illegible]	[illegible]	[illegible]
27	1	0	16	66	0	0	0	14	2	0	0	1	46.6	1707[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16	1	1	0	0	35.0	961[illegible]	[illegible]	[illegible]
2999	1	5	11	33	0	2	0	0	47	0	1	0	[illegible]	[illegible]	[illegible]	[illegible]
3000	1	0	42	51	0	0	2	0	2	1	0	1	79.6	4971.1	Kaolinite	Ex



Coalescence

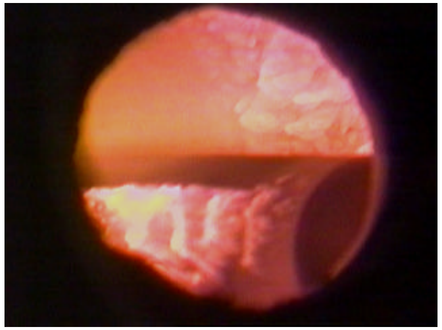
Composition												Ave. Diameter	Area	Chemical Category
Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ba	Ti			
0	0	2	29	1	1	0	1	63	1	1	1	8.3	54.0	Ca Silicate

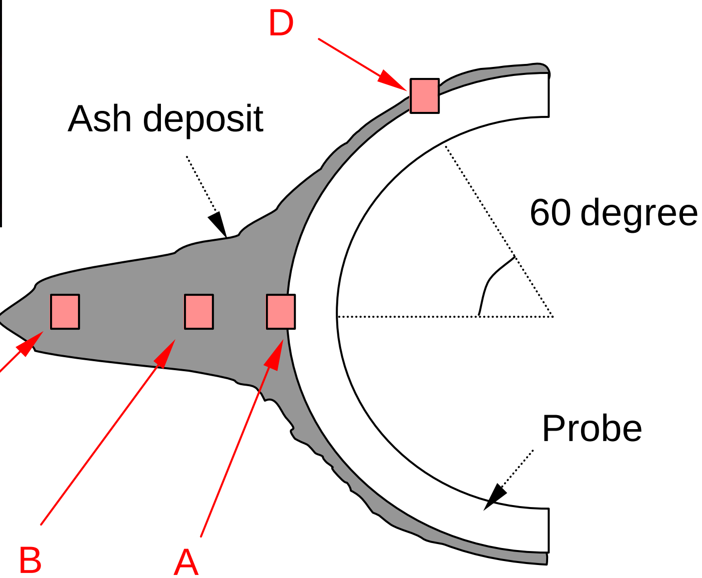


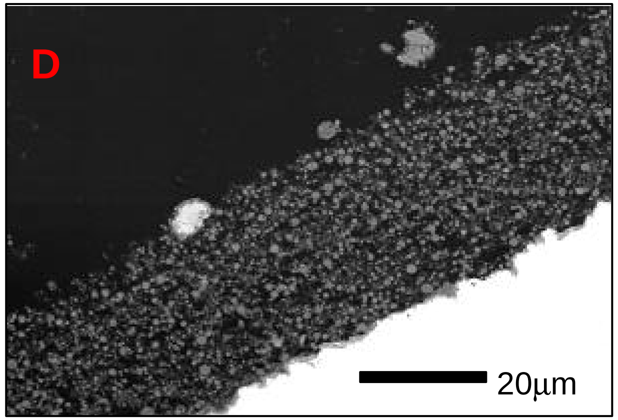
Fragmentation

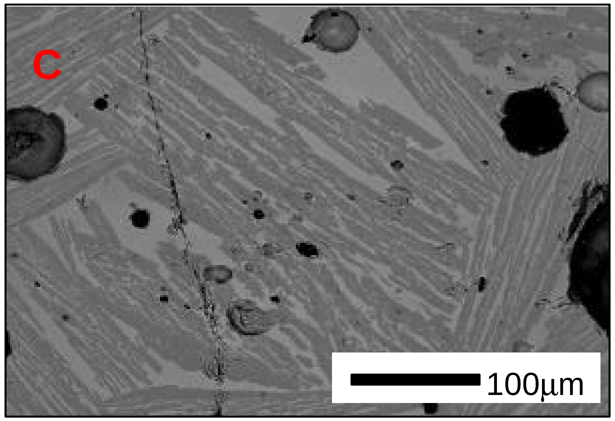
Composition												Ave. Diameter	Area	Chemical Category
Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ba	Ti			
0	0	0	97	0	0	0	1	0	0	2	0	1.9	2.8	Quartz
0	0	0	97	0	0	0	1	0	0	2	0	2.7	5.6	Quartz
0	0	0	97	0	0	0	1	0	0	2	0	2.3	4.0	Quartz

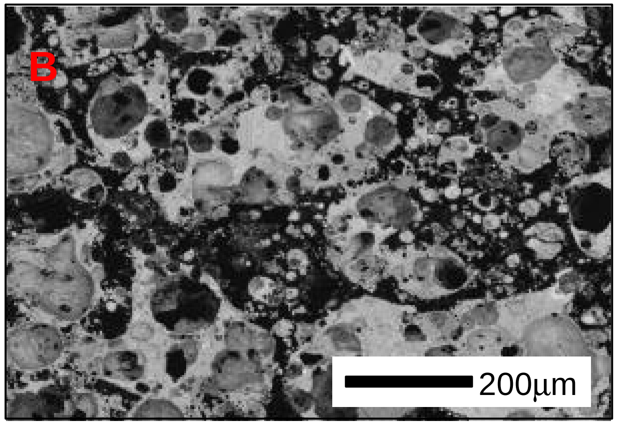
ASH DEPOSITION

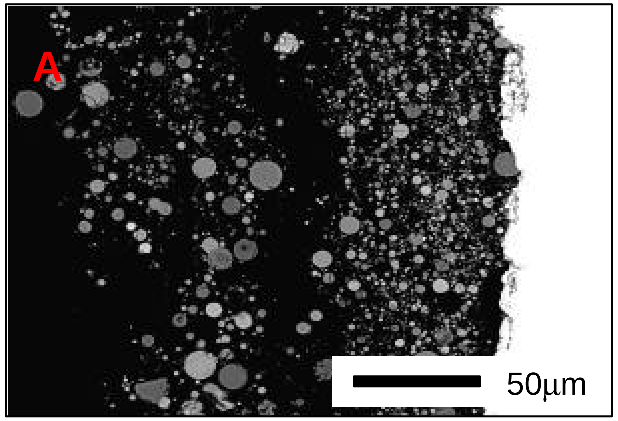






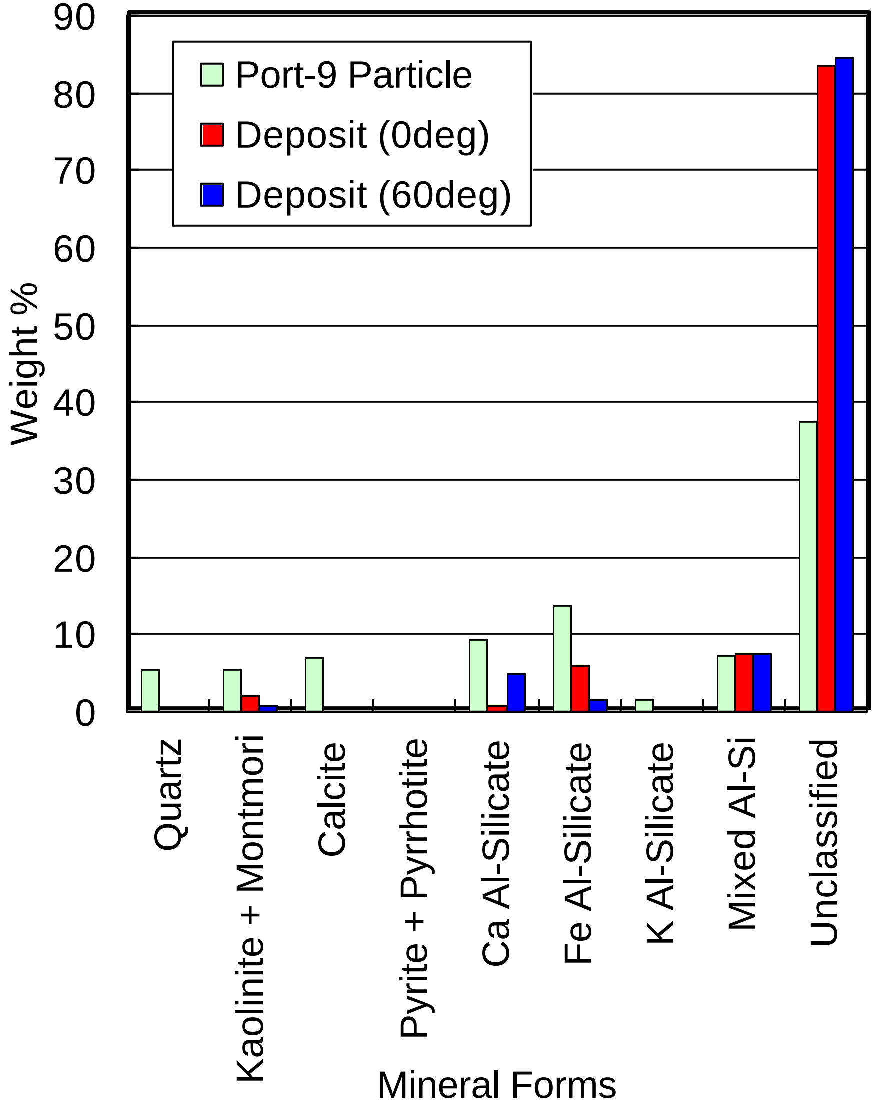




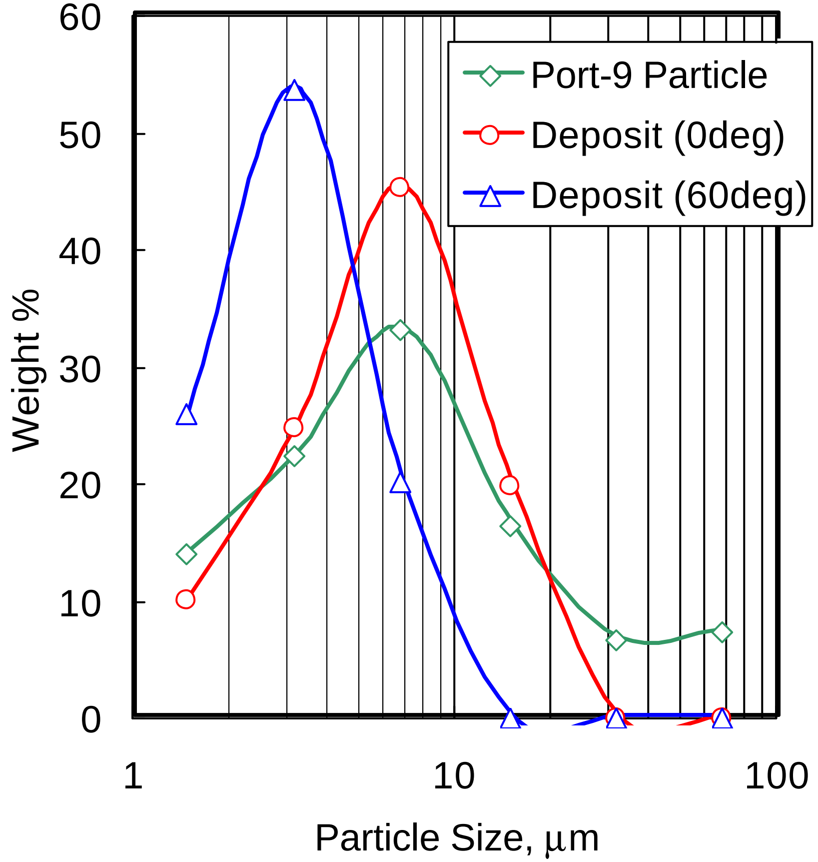


ATTACKING PARTICLES AND DEPOSITS

Chemical Forms



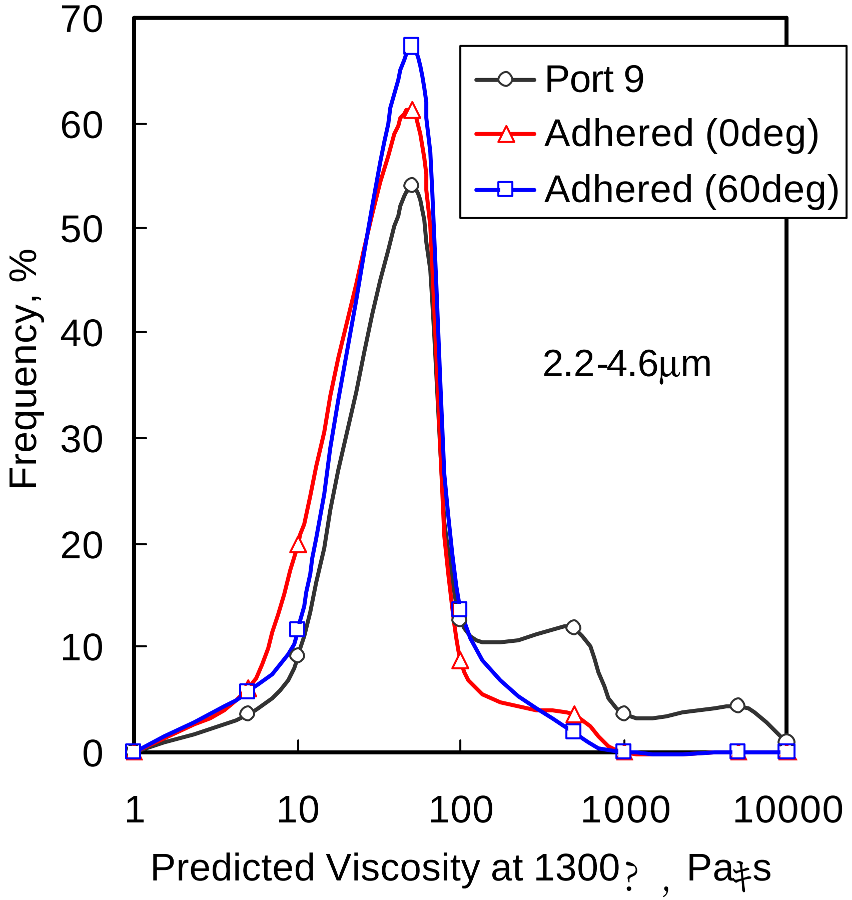
Size Distribution



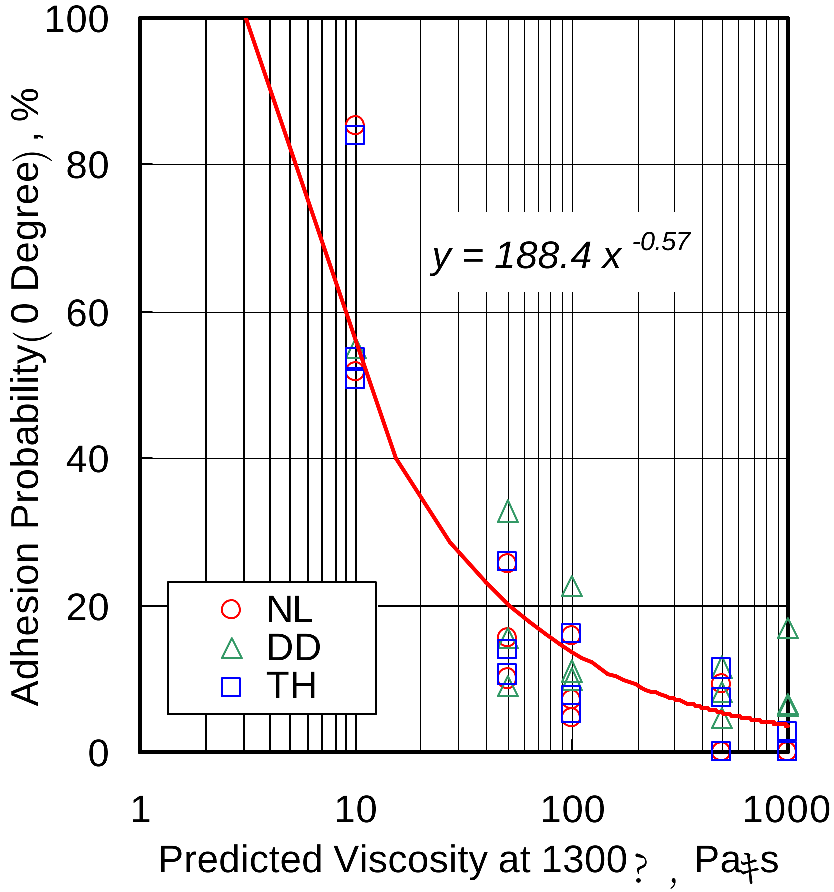
Low fusion-temperature fine ashes selectively adhered at the probe surface.

ASH ADHESION PROBABILITY

Viscosity Distribution



Adhesion Probability

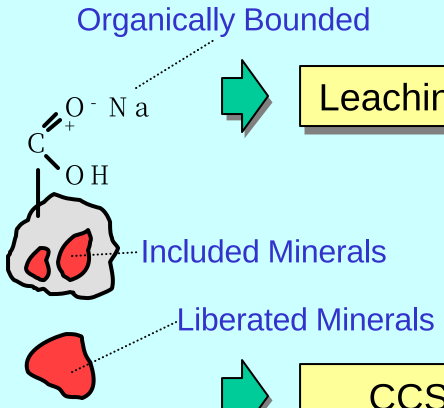


High viscosity particles do not exist in the deposit.

Viscosity prediction of each particle allowed the distinction of adhesion.

ASH MODEL AT GASIFIER

Analysis of Inorganics

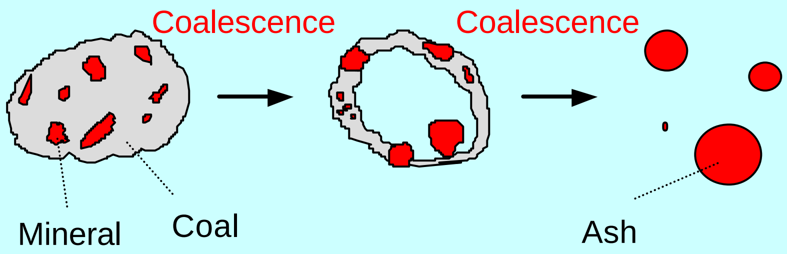


Leaching Test

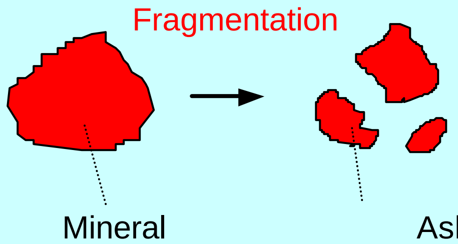
CCSEM

Ash Formation Model

Included Minerals



Excluded Minerals



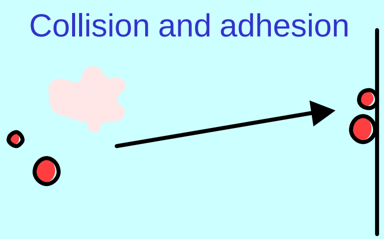
Predict size and chemical composition of ash particles

Viscosity Prediction

Kalmanovitch-Frank Model

$? = AT\, e^{1000 ‡B/T}$

Distinction of Adhesion

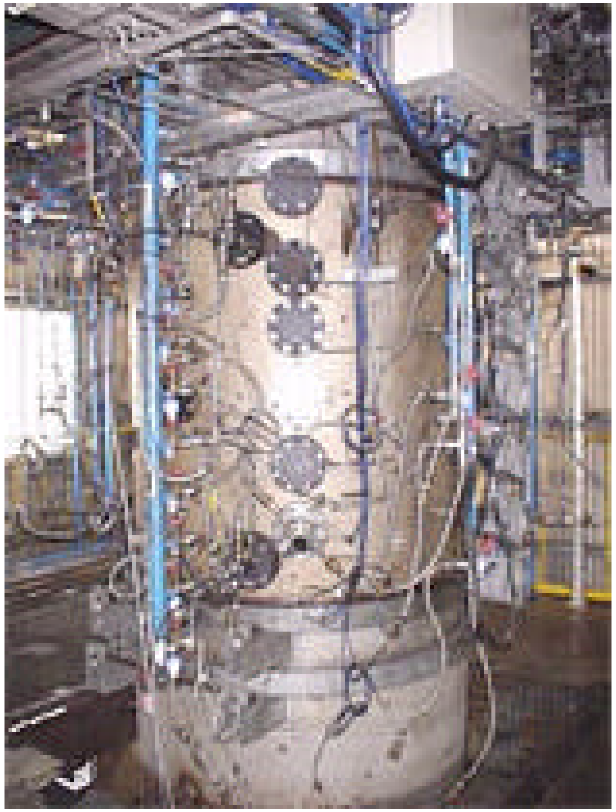


Adhesion Probability

$Pad = 188.4‡ (?_T)^{-0.57}$

ADHESION AT HEAT EXCHANGER

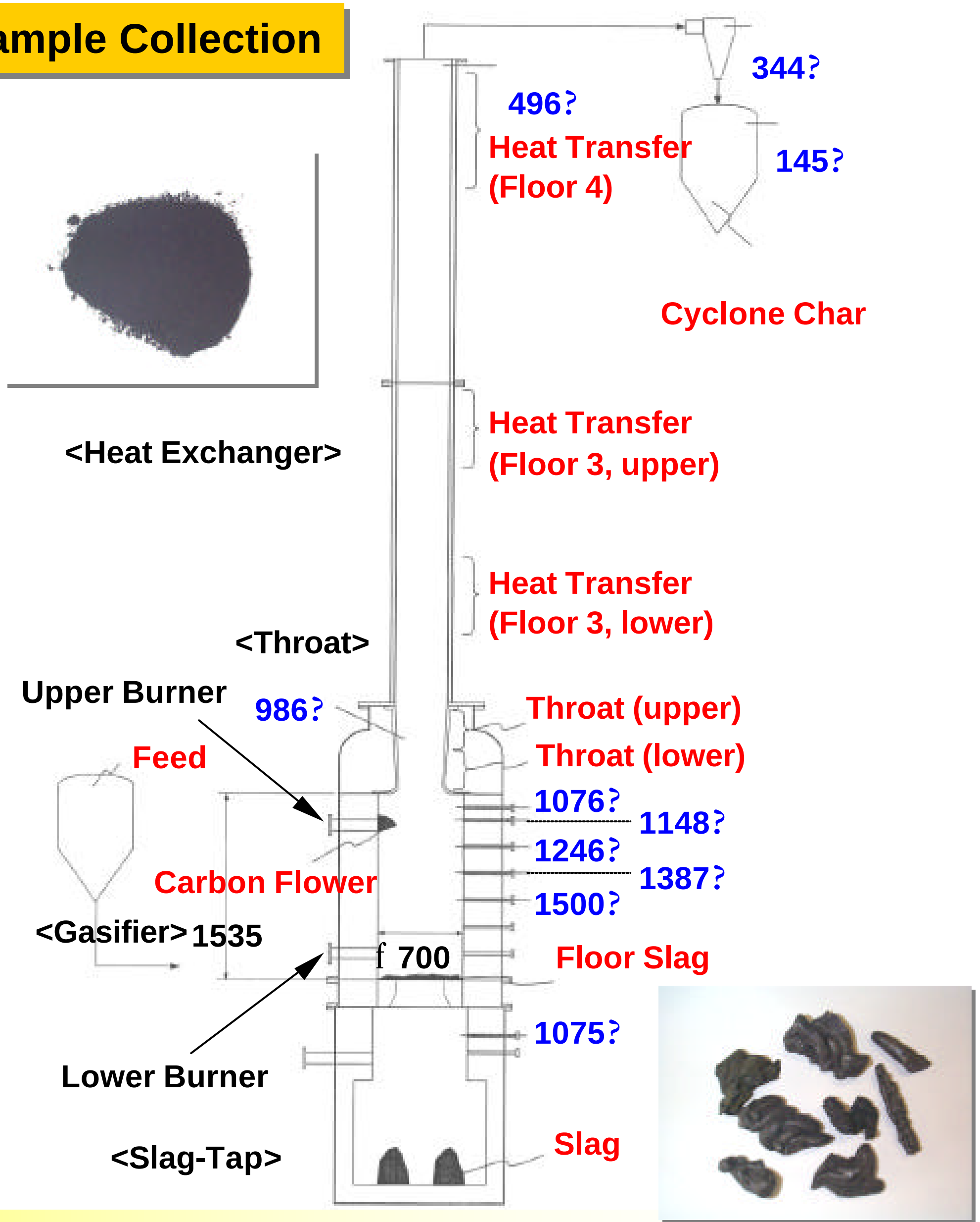
3ton/day gasification plant



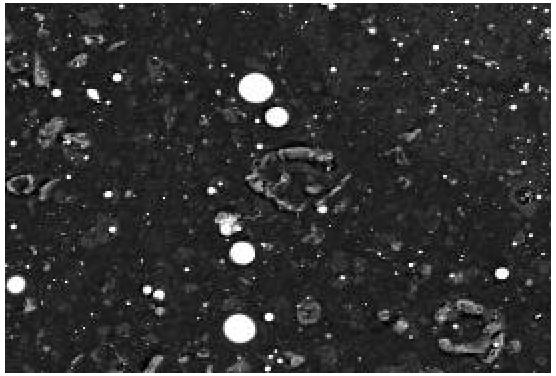
Oxygen-blown and two-step spiral flow gasification plant.

Dimension is same as HYCOL plant.

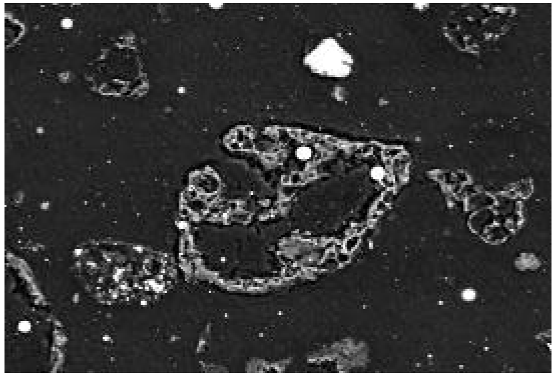
Sample Collection



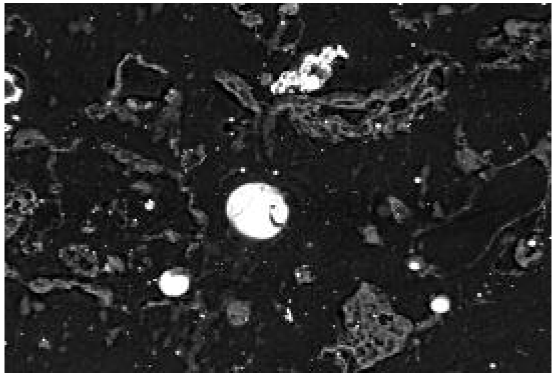
CROSS SECTION OF DEPOSITS



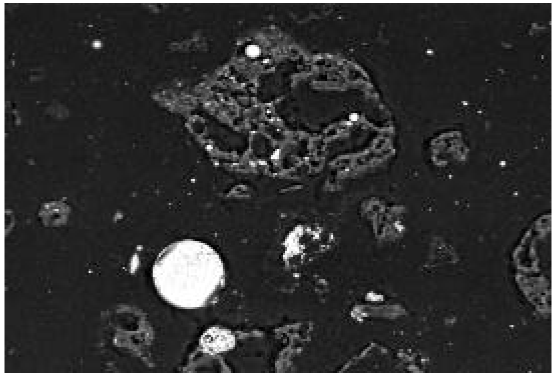
Cyclone Char



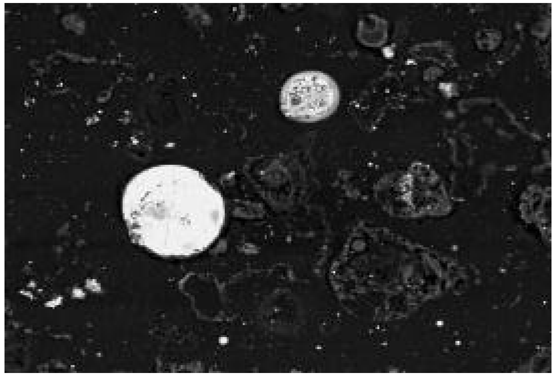
Heat Transfer (4th floor)



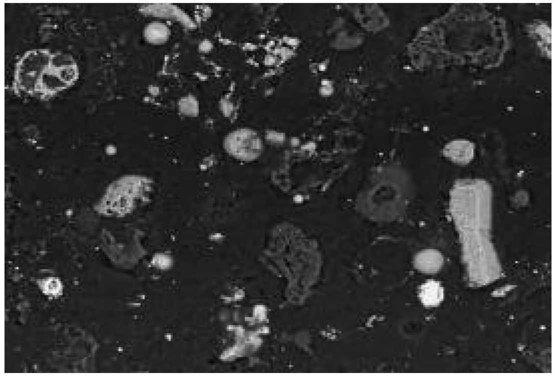
Heat Transfer (3rd floor, upper)



Heat Transfer (3rd floor, lower)



Throat (upper)

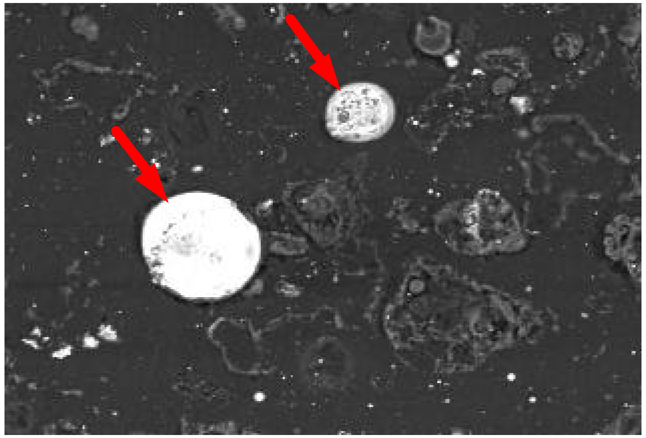
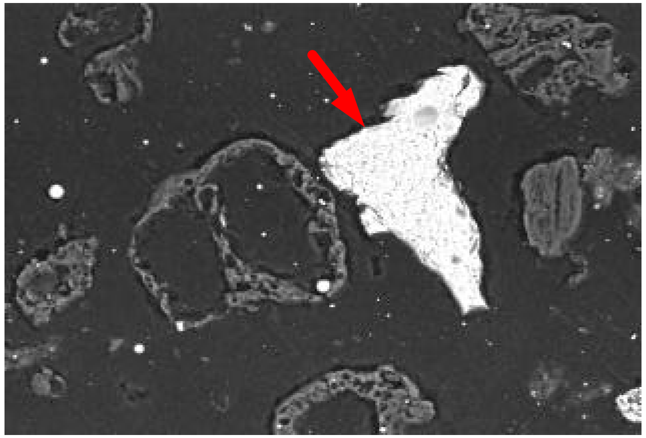
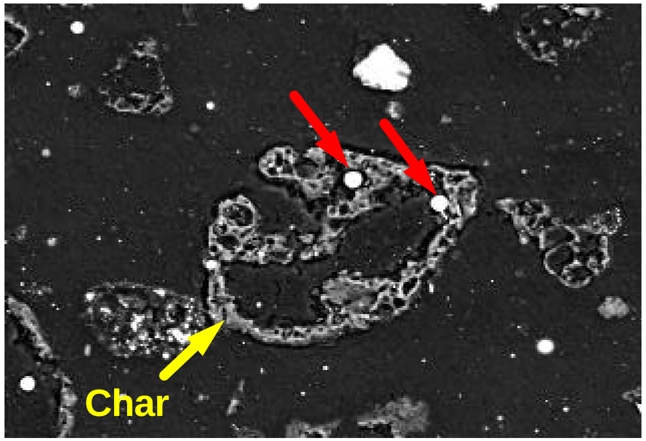
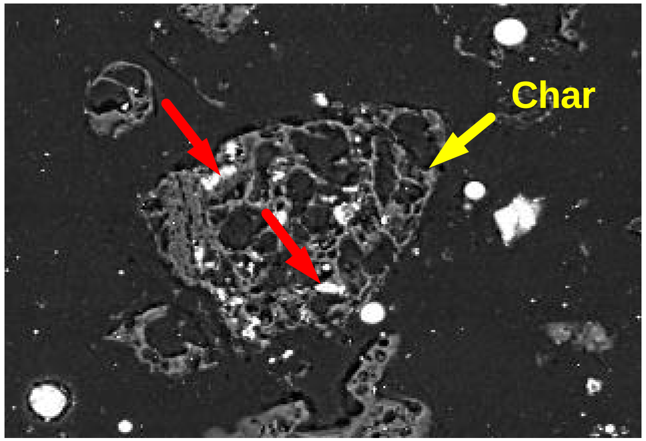


Throat (lower)

50μm

Round shape and rather large ash particles are observed at upper and lower throat. Mixture of balloon type char and melted round shape or non-melted angular shape ashes are observed in other samples.

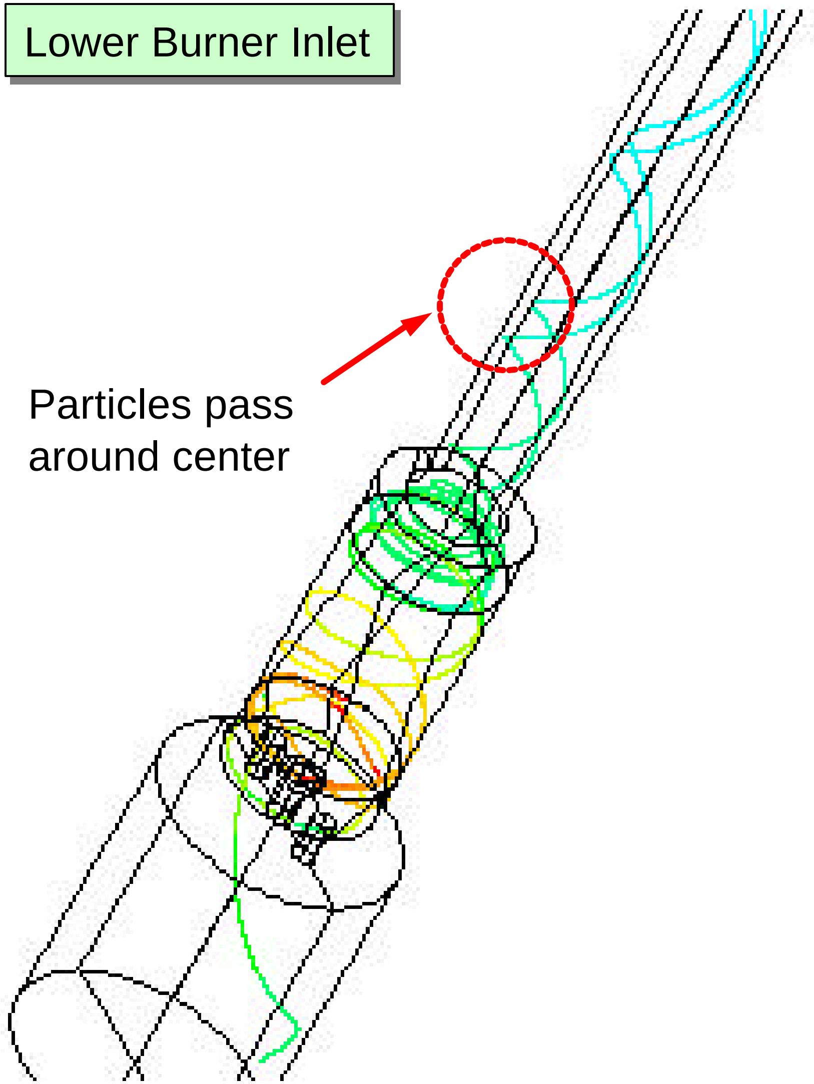
CLASSIFICATION OF ASH

	Melted	Non-Melted
Exclude		
Include		

5 0 ｵm

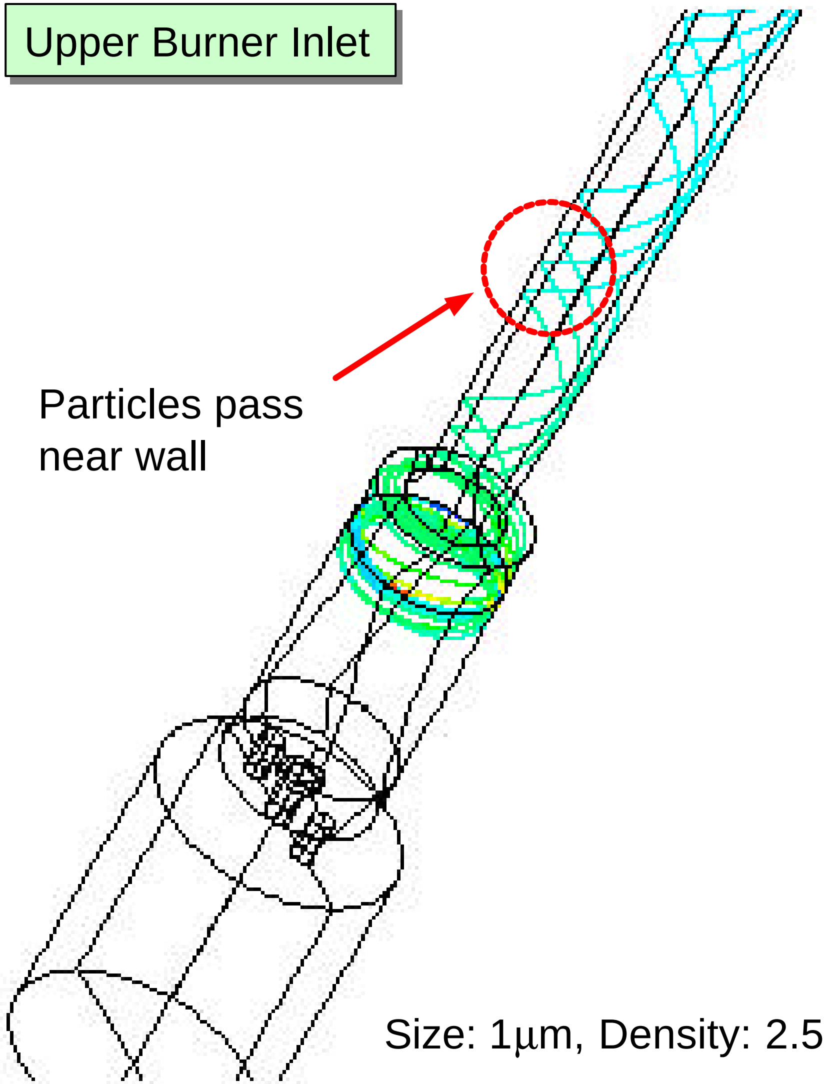
PARTICLE TRAJECTORIES

Lower Burner Inlet



Particles pass around center

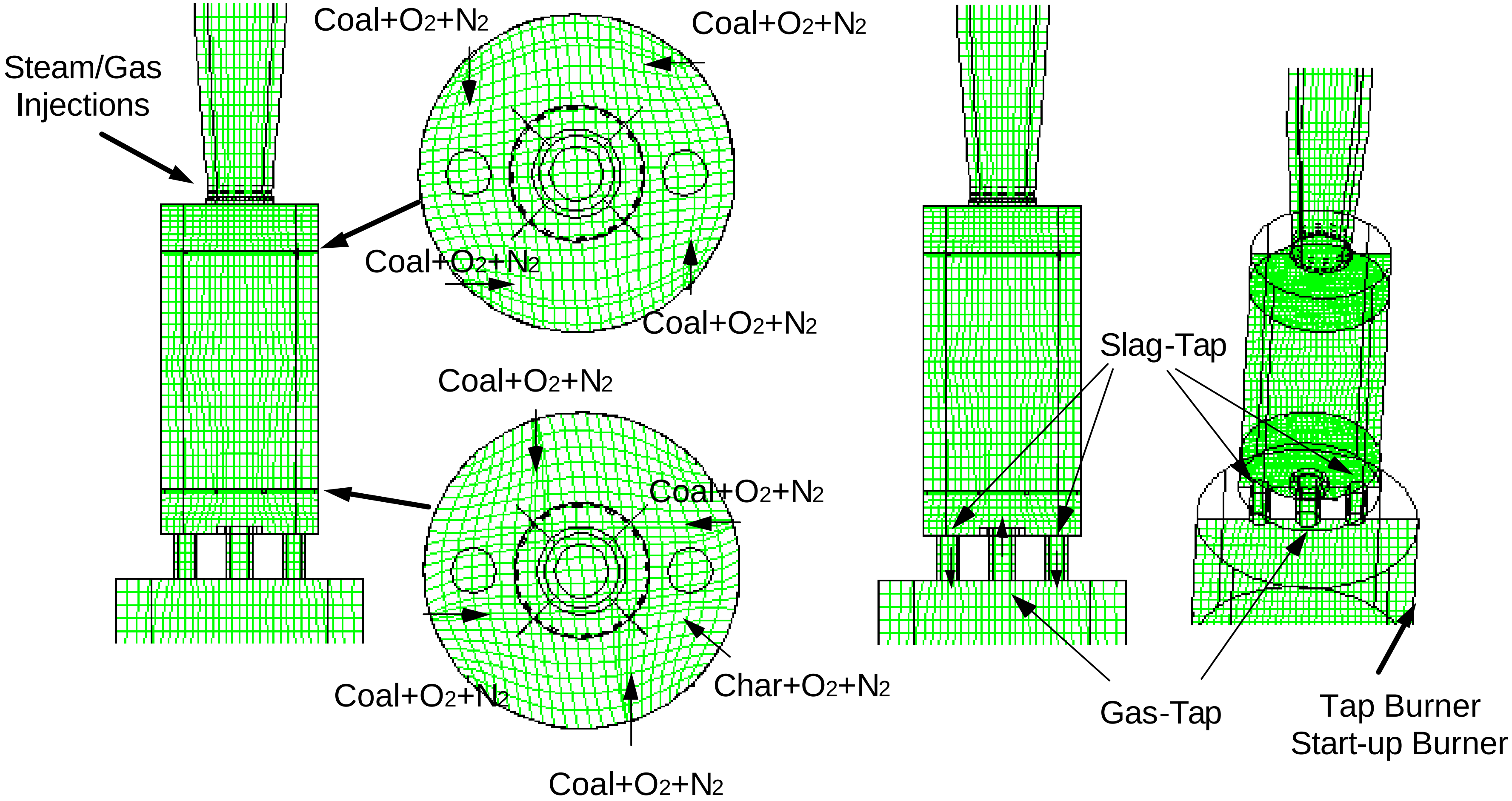
Upper Burner Inlet



Particles pass near wall

Size: 1μm, Density: 2.5

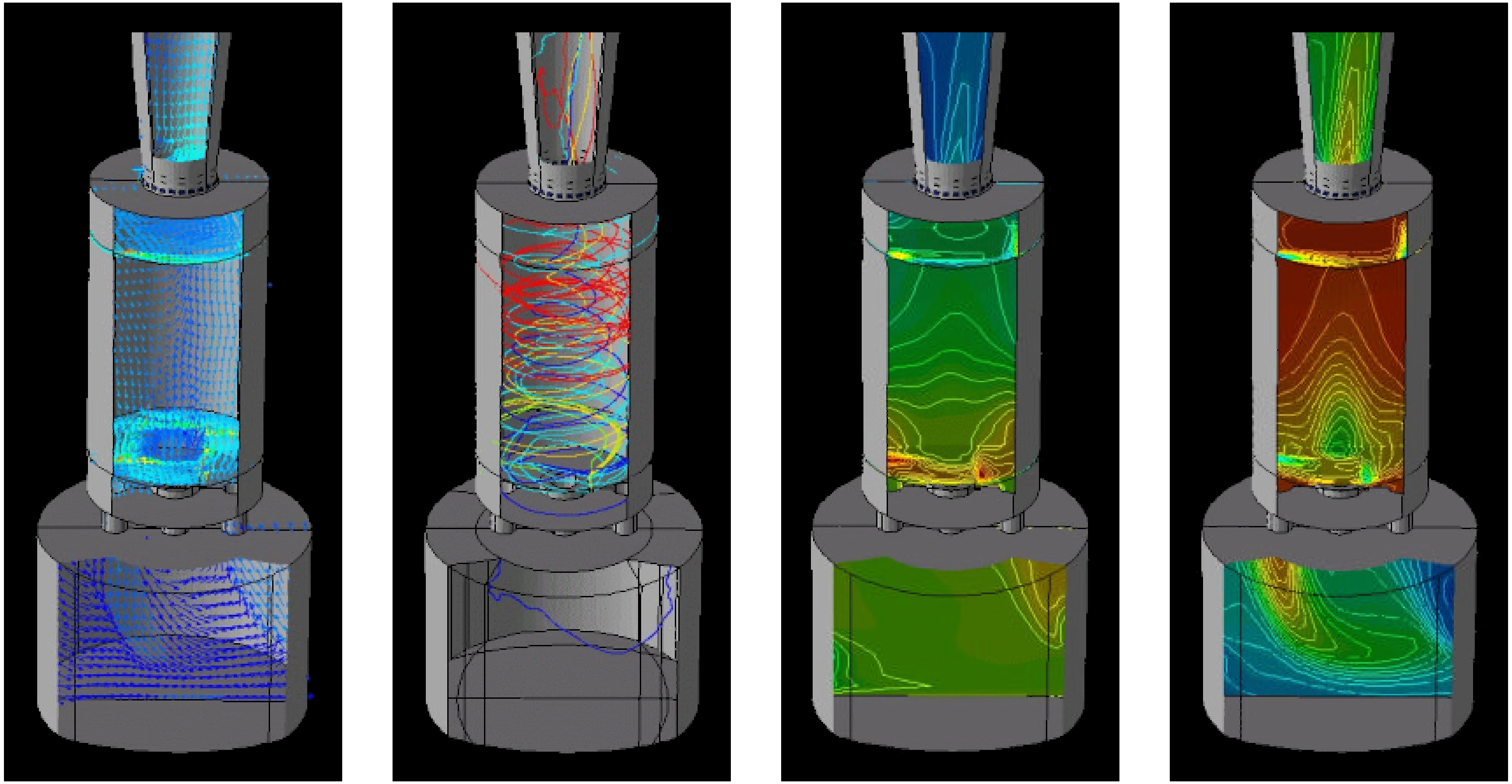
GEOMETRY OF HYCOL GASIFIER



Initial stage of a simulator development was carried out for the HYCOL plant. Pulverized coal and oxygen are both tangentially introduced into a gasification reactor through multiple burners installed at upper and lower levels.

GASIFICATION SIMULATOR

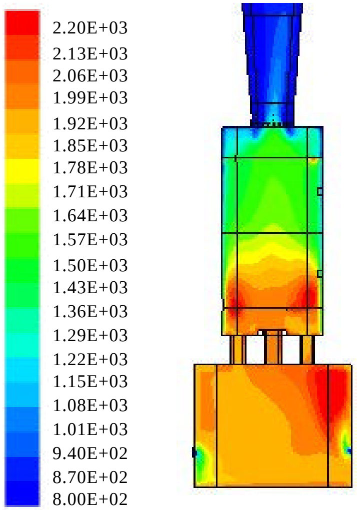
Gas velocity | **Particle trajectory** | **Temperature** | **CO rate**



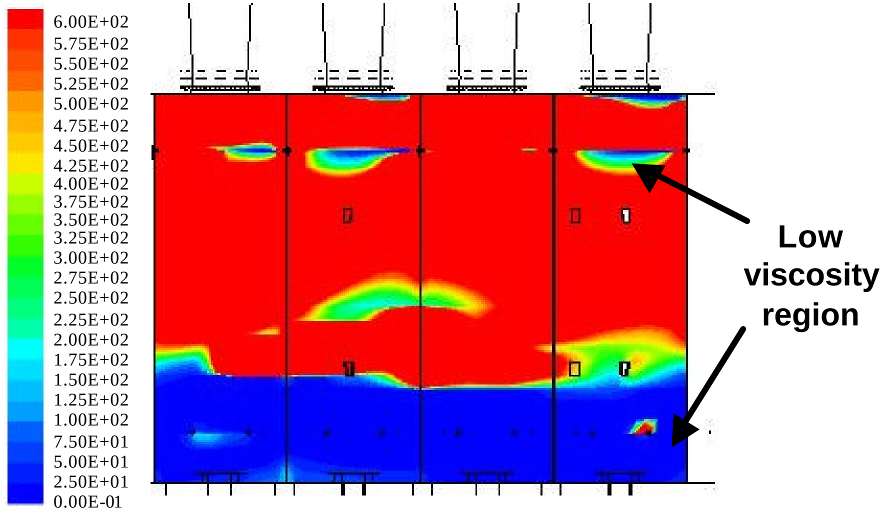
Numerical computer simulation model for an entrained-flow coal gasifier has being developed based on the commercially available CFD code, “FLUENT”.

CALCULATION LOOP

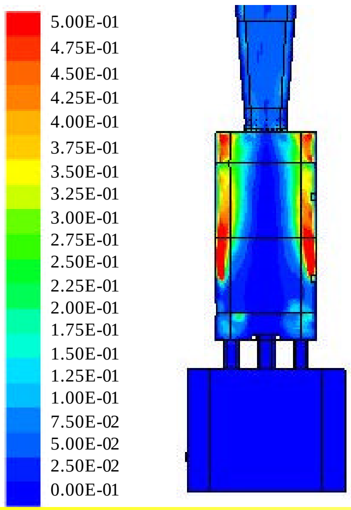
Temperature Profile



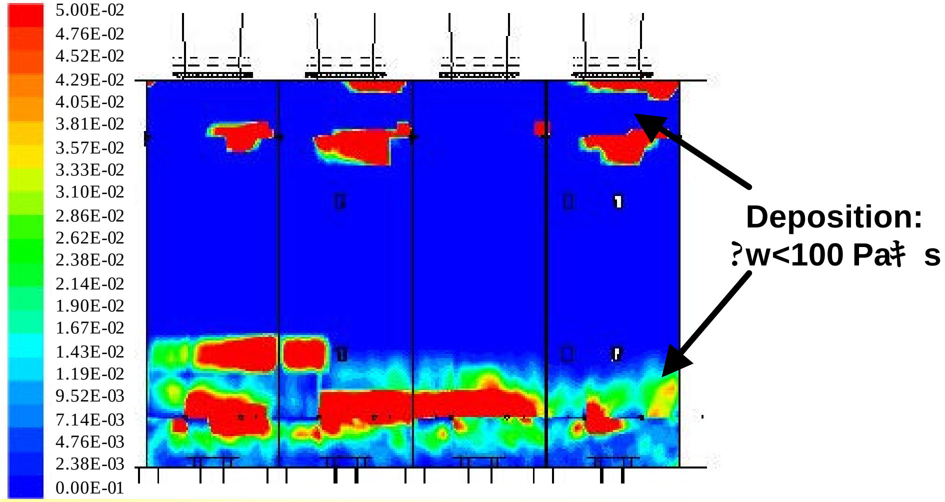
Ash Viscosity on Wall



Particle Concentration



Ash Deposition Rate on Wall

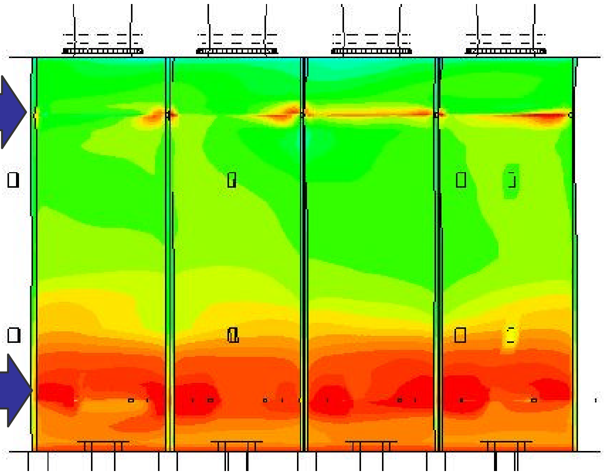


CHANGE OPERATING CONDITIONS

Temperature Profile near Wall

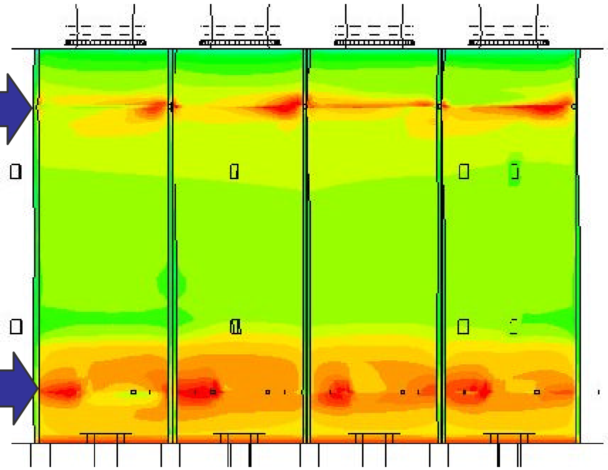
O_2/COAL =0.65

O_2/COAL =1.18

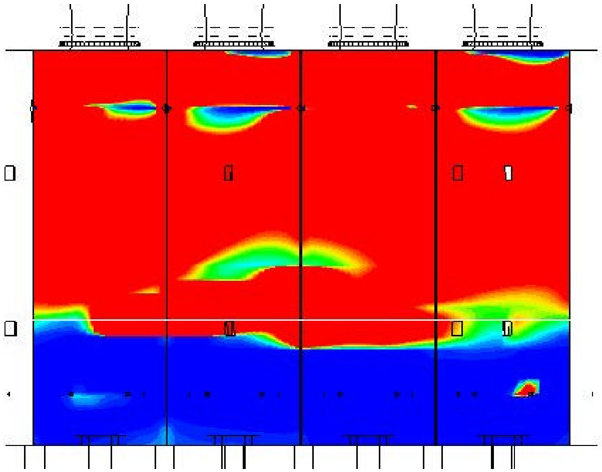


O_2/COAL =0.83

O_2/COAL =1.00

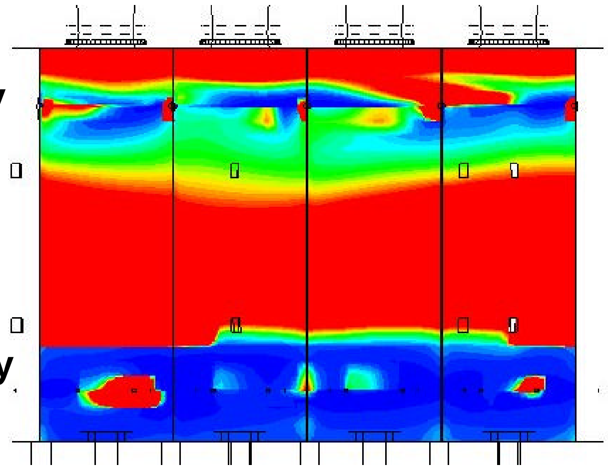


Ash Viscosity on Wall

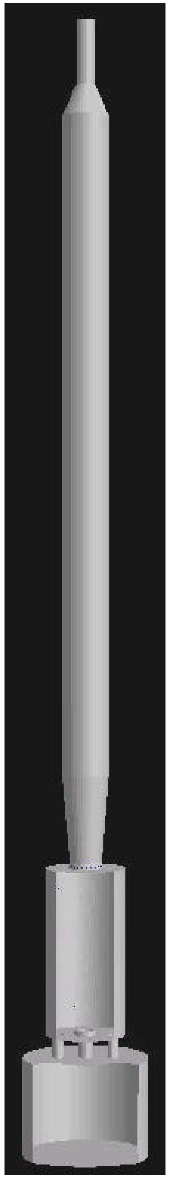


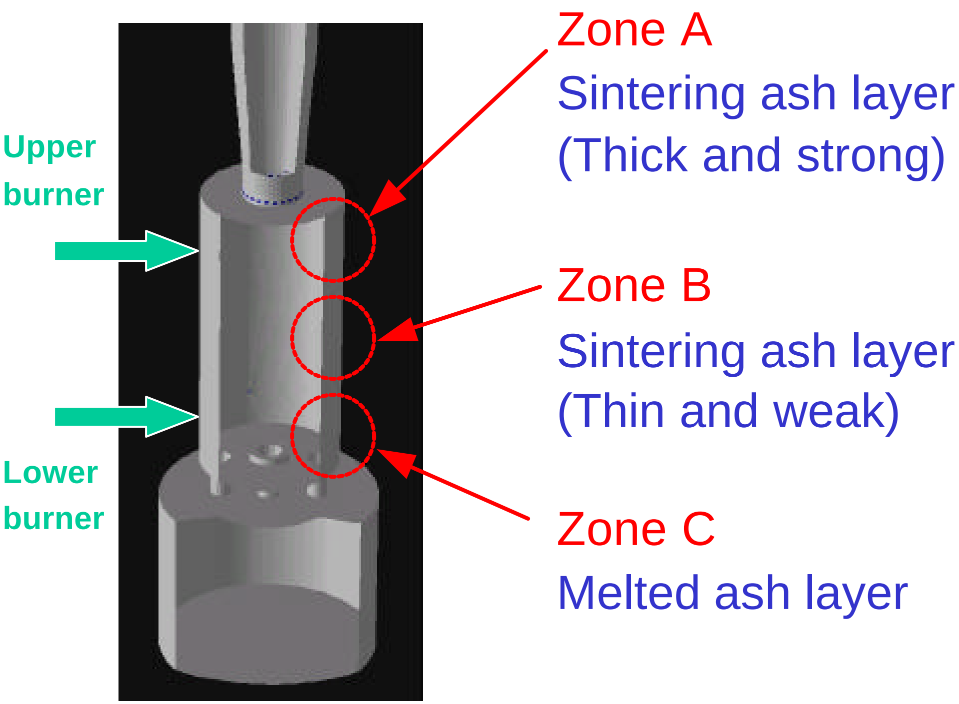
Low viscosity area expand

High viscosity area appear

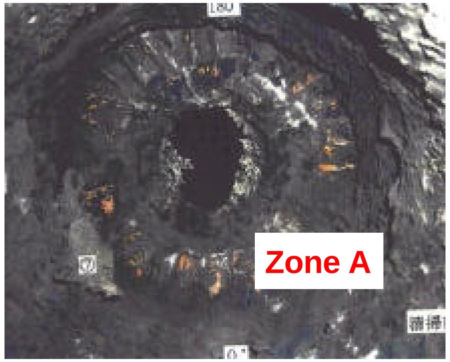


ASH DEPOSITION IN HYCOL GASIFIER

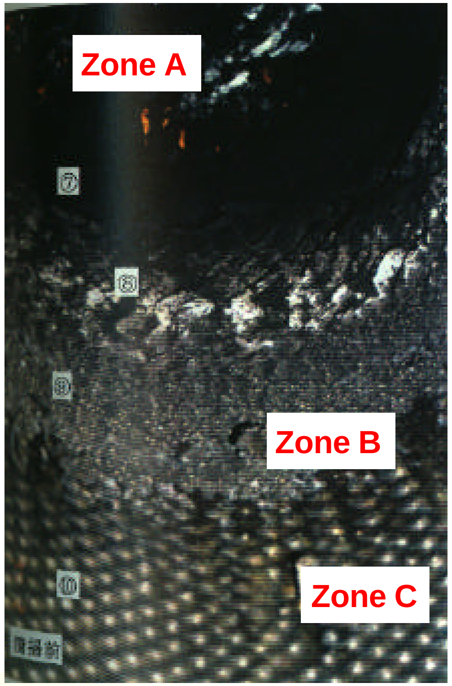




Slagging at Throat



Sintered Layer

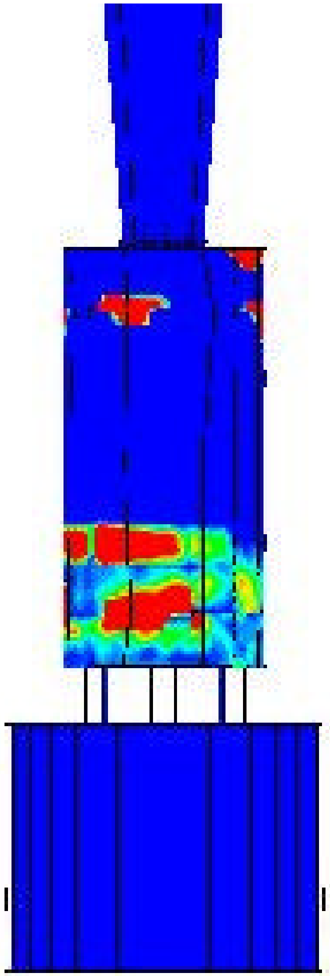


Thick sintered deposit appeared and plugged the throat area (Zone A) in some operating condition.

There was a thin sintered layer without slagging between upper and lower burner. (Zone B)

Lower burner level was regarded as a region where melted ash layer was formed. (Zone C)

CONCLUSION



Ash behavior sub-models based on mineral transformation and ash viscosity was newly incorporated into the modern computational fluid dynamics code “FLUENT”.

Calculated results gave a good agreement with the actual data measured at 50 ton/day HYCOL pilot plant.

Modified “FLUENT” can predict the ash deposition profiles fairly accurately with actual plant. Also, this simulator was available to use operation studies.

Further developments to improve the accuracy and the generality have being carried out at the Phase 2 stage of BRAIN-C project.

We believe this R&D program that aims a numerical computer simulator will reduce technical obstacles for the scale-up and commercialization of coal gasification technology.